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Solving multi-objective facility location problem using the fuzzy analytical hierarchy process and goal programming: a case study on infectious waste disposal centers

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ABSTRACT

The selection of a suitable location for infectious waste disposal is one of the major problems in waste management. Determining the location of infectious waste disposal centers is a difficult and complex process because it requires combining social and environmental factors that are hard to interpret, and cost factors that require the allocation of resources. Additionally, it depends on several regulations. Based on the actual conditions of a case study, forty hospitals and three candidate municipalities in the sub-Northeast region of Thailand, we considered multiple factors such as infrastructure, geological and social & environmental factors, calculating global priority weights using the fuzzy analytical hierarchy process (FAHP). After that, a new multi-objective facility location problem model which combines FAHP and goal programming (GP), namely the FAHP-GP model, was tested. The proposed model can lead to selecting new suitable locations for infectious waste disposal by considering both total cost and final priority weight objectives. The novelty of the proposed model is the simultaneous combination of relevant factors that are difficult to interpret and cost factors, which require the allocation of resources.

1. Introduction

Infectious waste disposal (IWD) remains an important problem affecting the social and medical domains of nearly every nation, and infectious waste (IW) is one kind of hazardous waste. This waste, which is generated in the diagnosis, treatment or immunization of human beings or animals, needs to be handled with careful consideration to prevent the spread of pathogens and to protect environmental health [1,2]. At present in Thailand, there are more than 37,000 medical institutions, and the amount of infectious waste is about 23,725 tons per year, while this waste is expected to increase by 5.5 percent per year [3]. Although public hospitals in Northeastern Thailand have their own incinerators to dispose of their waste, because of environmental concerns and protests by local residents, many incinerators inside hospitals have been shut down, and these hospitals finally need to use services from outside waste disposal agencies. Existing agencies are not able to dispose of existing infectious waste effectively. Consequently, building new, suitable facilities for IWD more effectively is becoming an issue that is particularly important to consider. In the past, infectious waste disposal has caused many problems, such as illegal dumping and lack of hygiene, and community hospitals are one of the medical institutions that have often found common problems because they are far from the locations of service providers or outside waste disposal agencies. For this reason, local governments of Thailand have set up a policy to encourage the establishment of new disposal centers by integration of neighborhoods, in order to increase the efficiency of IWD. The new disposal centers must be compatible with the requirements of governmental regulations, and at the same time must reduce economic, environmental, health and social impacts. Legally, municipalities are responsible for IWD. Therefore candidate locations will be selected from possible locations to serve medical institutions in municipalities. Choosing suitable locations (disposal centers) for this case poses complex problems, because we must consider social, environmental, cost and geological impact. The disposal site must not cause damage to the biophysical environment and the ecology of the neighboring area. In this problem, the maximization of satisfaction level regarding relevant impact, such as social and environmental impact, is as important as minimization of total cost. The satisfaction level regarding relevant impact can be evaluated from various qualitative and quantitative aspects, such as infrastructure,

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geological, environmental and social etc. The higher the satisfaction level, the lower the probability that sites cause damage to the biophysical environment and the ecology of the neighboring area. Certainly, both perspectives of total cost and relevant impact definitely must be considered in designing an optimal location network.

From the literature reviewed, location selection for IWD centers is an issue with many relevant factors, including factors that are difficult to interpret, and cost factors that require simultaneous allocation of resources. In order to achieve an optimal location network, the fuzzy analytic hierarchy process (FAHP) is suitable for solving multi-criteria/objective decision making (MCDM) problems that are difficult to interpret, and goal programming (GP) is suitable for solving multi-objective problems that require allocation of resources. Hence, choosing integrated FAHP and GP techniques (FAHP-GP model) to solve multi-objective facility location problems, while minimizing total cost and maximizing total location weight, are reasonable for use in this case. The multi-size location problem model (MSLP model) proposed in this study is different from the traditional facility location problem model (FLP model) because it can select both multiple sizes and locations simultaneously. In addition, the FAHP-GP model tries to minimize the total cost of the location network and maximize the satisfaction level of its stakeholders, under relevant constraints existing in the decision environment. Unlike the traditional FLP-based lowest total cost/minimum total distance, this can help the location network to reduce costs, increase efficiency and flexibility, and enhance the satisfaction level of stakeholders.

The rest of the paper is organized as follows. Section 2 is Related Literature. Section 3 is Methodology, Section 4 is Application of the proposed methodology and finally, Section 5 is the Conclusion.

2. Related literature

The facility location problem (FLP) has been studied for one hundred years, but formally it is accepted by all scientists that Alfred Weber's book of 1909 is the essential origin of this theory [4]. Traditional FLP involves taking the cost minimization as a single objective/criterion, using a mathematical model to solve a location network or transportation network (depots, customers and arcs) problem. The location network that incurs the minimum total distance or lowest total cost is regarded as an optimal solution. In traditional FLPs, many researchers [5–10] have often proposed cost/distance minimization as a single objective/criterion using mathematical techniques (heuristic and optimization techniques) for solving these problems. However, with some special problems, such as choosing places to dispose of hazardous waste, selecting sites for nuclear power plants, site selection for garbage disposal and location selection for IWD, location selecting locations for these problems are very important decisions because they are costly and difficult to reverse. The location selection problems in these cases are multi-criteria/objective decision making (MCDM) problems, namely multi-criteria/objective facility location problems (MCFLPs/MOFLPs), and the selection needs to consider the importance of relevant factors such as social responsibility and environmental awareness simultaneously. Consequently, one of the most essential difficulties in dealing with these problems is to find a suitable approach by which to evaluate these criteria.

In recent years, many techniques to solve MCDM problems have been proposed, including mathematical techniques (mathematical programming techniques and artificial intelligence techniques) and MCDM techniques. A group of researchers [11–16] have proposed mathematical techniques in order to deal with environmental restrictions, whereas another group [17–20] have often proposed MCDM techniques to solve MCDM problems that are difficult to interpret. One MCDM technique often suggested for solving these complex problems is AHP, because it is a simple and powerful approach [21,22]. Due to the complexity of the decision-making environment and ambiguity of each problem, some researchers [23–29] have proposed using AHP-only or combined AHP-other techniques for solving MCDM problems, because considering only the cost aspect will not handle these problems effectively. AHP has been widely used in the MCDM process by academics and practitioners [30–32] over the last 20 years. Since AHP alone will not be able to handle existing environmental restrictions, some researchers have combined AHP with mathematical techniques, in order to deal with environmental restrictions simultaneously. Linear programming (LP) and goal programming (GP), mathematical programming techniques, are often combined with the AHP in the literature. The LP model is used to solve single objective problems, but the GP model has been developed to solve multi-objective problems. GP was studied by Charnes, Cooper and Ferguson in 1955 for solving unsolvable LPs. For example, some researchers [33–38] have constructed combined AHP-mixed LP models for solving a single objective decision making problem, and combined AHP-mixed GP model for solving multi-objective decision making problems. Although AHP is a popular tool to solve MCDM problems, conventional AHP cannot reflect the human thinking style. The conventional AHP method is difficult in that it applies an exact value to express the decision maker's opinions in a comparison of alternatives, and the AHP method is often criticized because of its use of an unbalanced scale of judgment, and its inability to adequately handle the inherent uncertainty and imprecision in the pair-wise comparison process [39]. Later, the fuzzy analytic hierarchy process (FAHP), based on the fuzzy set theory of Zadeh [40], was developed in order to overcome this weak point, and this technique is often used to replace conventional AHP to solve MCDM problems that are difficult to interpret. Hence, recently, many researchers have used FAHP to solve MCDM problems instead of traditional AHP [41–46]. Although FAHP is widely used to solve MCDM problems, there are few papers that report combined FAHP-mathematical techniques to solve MCDM under existing environmental restrictions. For example, He et al. [47] proposed a FAHP-LP model for the multi-criteria transshipment problem to maximize customer service level, while minimizing logistics costs at the same time. Kannan et al. [48] presented an integrated fuzzy multi criteria decision making method and GP approach for supplier selection and order allocation in a green supply chain. Also, Bakeshlou et al. [49] proposed evaluating a green supplier selection problem using a hybrid MODM algorithm, in order to effectively consider existing environmental restrictions.

In MCFLPs/MOFLPs, some researchers have recently proposed to use the FAHP for solving the FLPs in many ways. For example, Önüt et al. [50] proposed a combined fuzzy MCDM approach based on the FAHP and fuzzy TOPSIS techniques for selecting a suitable shopping center location. Nazari et al. [44] applied Chang's fuzzy AHP-based multiple attribute decision-making (MADM) method for selection of the best site for landfills. Choudhary and Shankar [51] proposed the STEEP-fuzzy AHP-TOPSIS framework for evaluation and selection of thermal power plant locations. Safari, Faghih, and Fathi [52] proposed a fuzzy approach for selection of facility locations using technique for order preference by similarity to ideal solution (TOPSIS) method. Recently, Ozgen and Gulsun [53] proposed a combined probabilistic linear programming and fuzzy AHP for solving the multi-objective capacitated multi-facility location problem. Safari, Soufi and Aghasi [54] proposed the hybrid fuzzy MCDM approach (Hybrid of F-DELPHI, F-AHP, F-LLSM and F-PROMETHEE) and applied it to select the location for a Hypermarket. Hanine et al. [55] proposed the comparison of the fuzzy TODIM and fuzzy AHP methods for landfill location selection.